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THE CHROMIUM RESOURCES OF ZIMBABWE

By D. SLATTER

A paper presented to the
International Economic Resources Conference on Zimbabwe
held in Salisbury, Zimbabwe from 1st-5th September, 1980

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CONTENTS

Page No

Introduction	1
Reserves of Zimbabwean ores and production	5
Properties of Zimbabwean ores for ferrochromium production	8
Physico-chemical ratings of the ores for smelting	12
Areas for further exploration and development	13
Metallurgical problems in ferrochromium production in Zimbabwe.	14
Conclusion	16
References	17

LIST OF TABLES

Table 1 : Types of ferrochromium alloys produced from chromium ores	2
Table 2 : Former classification and new classification of chromium ores	4
Table 3 : Official world reserves of chromium ores	5
Table 4 : Properties required in chromium ores for efficient production of high-carbon ferrochromium	9
Table 5 : Chemical groupings of Great Dyke chromium ores for smelting to ferrochromium alloys	11
Table 6 : Examples of physico-chemical ratings applied to the chromite seams on the Great Dyke and to the podiform deposits	13

LIST OF FIGURES

Fig. 1 : Projected growth of stainless-steel production ⁽⁴⁾	3
Fig. 2 : Chromium ore production and value in Zimbabwe from 1964 to 1979	7

Introduction

The potential of the chromium resources of Zimbabwe is governed by the uses and world demand for this metal. The main use for chromium ores is the production of ferrochromium alloys which supply chromium to the steel industry for chromium alloy steels and stainless steels. The use of chromium ores for refractories and for the production of chromium chemicals is a far smaller market. In 1976, for example, approximately 70% of the chromium requirement in the United States was used in the steel industry, approximately 18% in the chemical and 13% in the refractory industries⁽¹⁾.

There is no known substitute for chromium in stainless steel. Although there are a wide variety of industrial materials which can substitute for stainless steel, there are generally limitations to these concerning either cost, performance or customer appeal. In some alloy steels, chromium may be replaced by metals such as Ni, Co, Cu, V and Mo, but the use of these is generally more costly and may also lower performance standards.

Thus the future of chromium is bound to the growth of the steel industry and particularly to the stainless steel industry which consumes 72% of the industry's chromium requirements. Predictions concerning the growth in world demand for stainless steel will, therefore, reflect very largely the potential demand for chromium. INCO reported that World production of stainless steel increased from 1,6 million tonnes in 1955 to 6,7 million tonnes in 1974, an annual growth rate of 7,7%⁽²⁾. The annual growth rate for steel over the same period was 5,5%⁽³⁾. This growth rate has not been maintained over the past

few years due to general world recessionary problems, and the present trend in the world steel industry and thus the ferrochromium industry is rather bleak. Nevertheless, it is reasonable to predict an average growth rate of 4,0% per annum for stainless steel, in which case by 1985 world consumption would be approximately 10 million tonnes and more than 18 million tonnes by 2000 A.D., Fig. 1⁽⁴⁾. This growth rate may be considered pessimistic. For example, Winship⁽⁵⁾ proposed a world growth rate of 8,2% for stainless steel, and Way⁽⁶⁾ proposed 10,4% per annum. Admittedly these were made when the industry was booming in 1974/75 but even the more pessimistic prediction gives three times the 1974 consumption of stainless steel by the year 2000 and this has important implications for chromium ore and ferrochromium production.

In order to be used by the steel industry, chromium ores are converted into various ferrochromium alloys, and these are summarised in Table 1.

Table 1 : Types of ferrochromium alloys produced from chromium ores

	composition.	production and remarks
on mium	basis 60% Cr (65-70% Cr); 4-8% C; 1,5% Si max.	submerged arc smelting of high Cr ore. ($Cr:Fe > 2,7$) C content depends largely on ore quality.
chrome	50-55% Cr; ~8% C > 2% Si	submerged arc smelting of high-Fe ores (low Cr:Fe)
on mium	65-75% Cr; 0,05-2,0% C; 1,5 % Si	Perrin Process or similar exothermic reaction between Fe Cr Si and lime/chrome ore melt
chrome	37-39% Cr ; 40-47% Si	submerged arc smelting of chrome ore and quartz

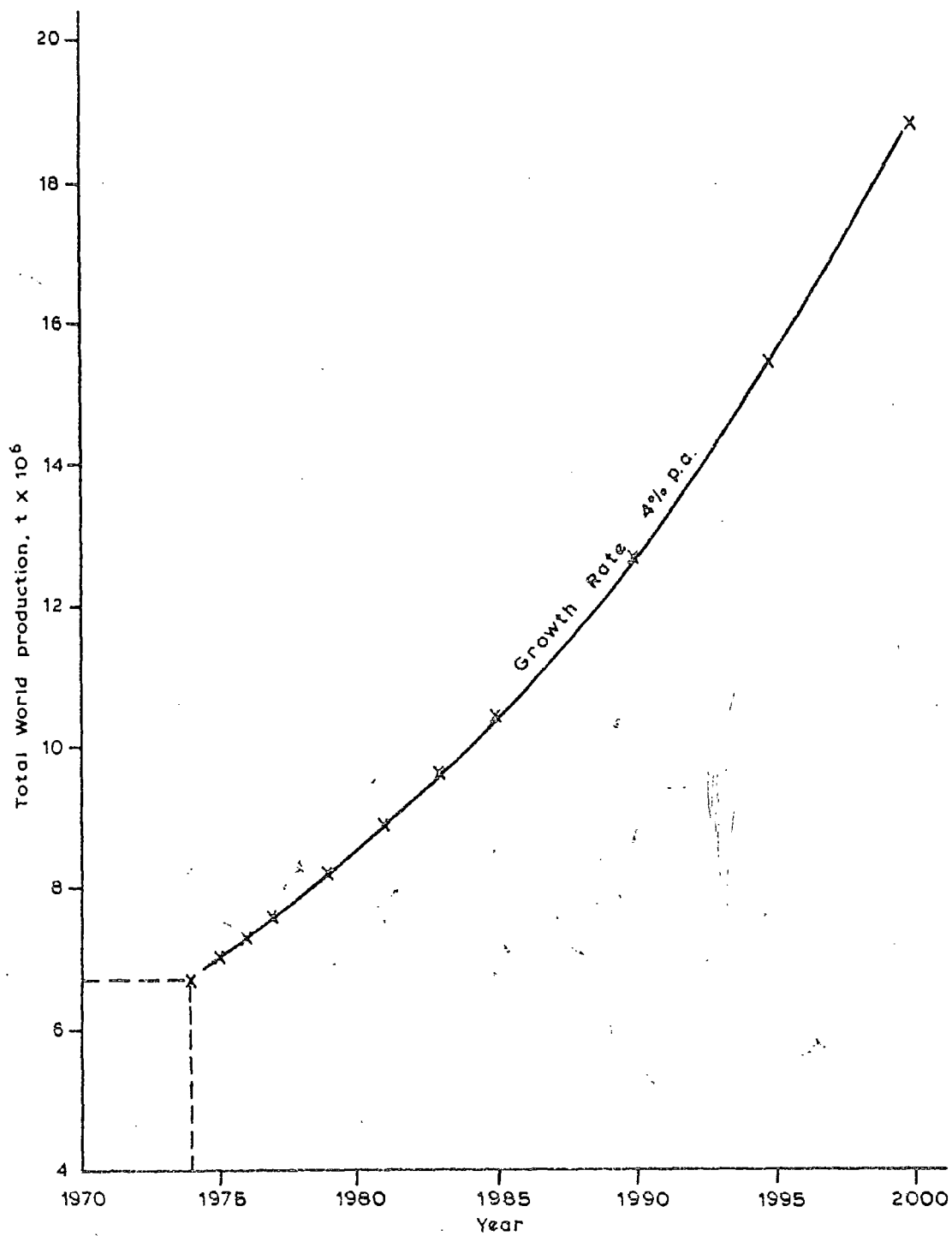


Fig.1: Projected growth of stainless-steel production.

Up until the early 1970's, the main industrial demand was for low-carbon ferrochromium due to the low carbon content required in stainless steel and to the fact that excess carbon could not be removed from the stainless steel melt without incurring large losses of chromium. However, the advent of the AOD process (argon-oxygen decarburising) radically changed the technology of stainless steel production by making it possible to remove carbon from the melt without losing chromium. Thus the stainless steel producers switched their demand to the less costly high-carbon alloys. Demand for high-carbon ferrochromium increased from 35% of total ferrochromium consumption in 1970 to 85% in 1978. In addition, the ability to remove carbon made the Cr:C ratio of the alloy less important, thus accounting for the advent of the so-called charge chrome alloys produced from ores with low Cr:Fe ratios. The strategic importance of the high Cr:Fe ratio metallurgical grade Zimbabwean ores was, therefore, lessened. There is still a distinct advantage in supplying ferrochromium with a high content of chromium but the price structure is now more competitive.

As a result of the changes in technology which enable the use of ferrochromium produced from ores not classified as metallurgical grade, it is appropriate to reclassify chromium ores on a different system, Table 2⁽⁷⁾.

Table 2 : Former classification and new classification of chromium ores

former classification	composition of ore	new classification
metallurgical grade	46% Cr_2O_3 ; Cr:Fe $\geq 2:1$	high-chromium
chemical grade	40-46% Cr_2O_3 ; Cr:Fe $\leq 2:1$	high-iron
refractory grade	$\geq 20\% \text{Al}_2\text{O}_3$; $\geq 60\% \text{Al}_2\text{O}_3 + \text{Cr}_2\text{O}_3$	high-aluminium

Reserves of Zimbabwean ores and production

Zimbabwe is the largest known source in the World of the high-chromium ores with officially published figures giving reserves of 560 million tonnes and a similar additional amount as potential further reserves. Reserves of high-chromium ores for the remainder of the World, including South Africa and the USSR, have been estimated at approximately 90 million tonnes with a potential of a further 87 million tonnes, Table 3⁽⁷⁾. Thus on these estimates Zimbabwe holds 85% of the World's known high-chromium ores. It should be emphasized, however, that estimates concerning the ore reserves of the USSR are very speculative and probably very conservative.

Estimated World reserves of the high-iron ores is 1200 million tonnes of which South Africa holds 1100 million tonnes and Zimbabwe 56 million tonnes, Table 3.

Table 3 Official world reserves of chromium ores⁽⁷⁾

ore type	reserves (tonnes $\times 10^6$)		
	Zimbabwe	South Africa	remainder
high-Cr	560	-----90-----	
high-Fe	56	1100	44

Thus 97% of the presently identified World reserves of chromium ores are in the Southern Africa sub-continent.

Reserves of the podiform ores in Zimbabwe are much less than the Great Dyke reserves, probably only 10-15 million tonnes, but confidential information indicates that the reserves of both high-chromium and high-iron ores on the Great Dyke are very much greater than the official estimates and may amount to more than 3000 million tonnes. The official estimates are based upon reserves calculated to an inclined depth of 200 metres only.

In 1977, cumulative primary chromium requirements for the World up to the year 2000 were estimated to be 89 million tonnes⁽⁷⁾. This corresponds to approximately 270 million tonnes of ore and as the non-Southern African reserves are estimated at 120 million tonnes there is a potential shortfall of approximately 150 million tonnes which will have to be met from either Zimbabwe or South Africa unless further substantial reserves are discovered elsewhere.

In this regard it is of interest that a recent publication, Mining Week of August 6, 1980, states "According to all indications, the reserves of other major producers like the Philippines, Yugoslavia and Albania are slowly starting to run out and possibly only non-viable reserves will be left in between five and ten years' time".

Figures have now been released by the Zimbabwean Central Statistical Office for the annual production of chromium ore in Zimbabwe from 1964 to the present, thus covering the period when these details were kept secret for political reasons, Fig. 2⁽⁸⁾. Annual production of chromium ore increased from 447000 tonnes in 1964 to a peak of 876000 tonnes in 1975. Production then decreased to 478000 tonnes in 1978 but showed a slight increase again to 542000 tonnes in 1979. The decrease in production was due probably to the effect of both the repeal of the Byrd Amendment in the United States and to the general decrease in demand for ferrochromium following the downturn in the World's steel industries. Although the tonnage for 1978 was very similar to that of 1964, the value of the production increased from approximately \$4,5 million in 1964 to \$13,5 million in 1978 reflecting increases in the price of the ore from approximately \$10/tonne in 1964 to approximately \$30/tonne from 1976 onwards.

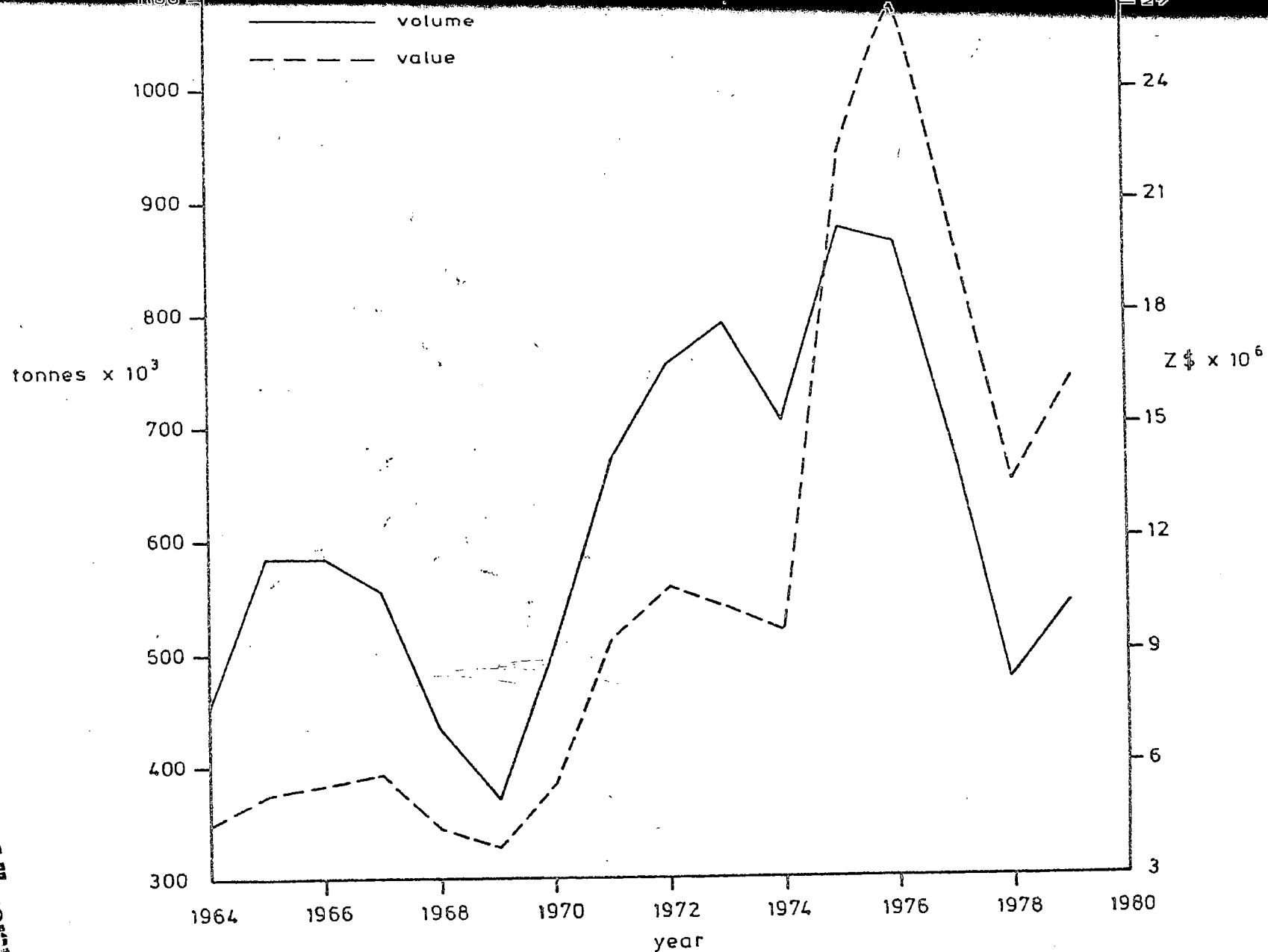


Fig 2 : Chromium ore production and value in Zimbabwe from 1964 to 1979.

A very large proportion of the chromium ore produced in Zimbabwe is processed into ferrochromium alloys, mainly high-carbon ferrochromium and ferrochromium silicon, with some low-carbon ferrochromium. There are two large producers at present in Zimbabwe, Rhodall belonging to Anglo American, and Rhomet belonging to Union Carbide, with fairly similar outputs in terms of total tonnage and a combined total output of approximately 235 000 tonnes/annum.

Total consumption of ore to produce this quantity of alloy is estimated to be approximately 517 000 tonnes. A total of 542 000 tonnes of ore was produced in 1979 and thus approximately 95% of Zimbabwe's ore production was converted into ferrochromium alloys and only 5% exported as the ores.

Accepting even the conservative estimate of 560 million tonnes of high-chromium ores in Zimbabwe, it is evident that at the present rate of production the reserves are sufficient for over 1000 years, 500 years if production is doubled, or 100 years at ten times the production. Thus the controlling factor in chromium ore or ferrochromium production in Zimbabwe will be not the reserves available but the world demand.

Properties of Zimbabwean ores for ferrochromium production

The chromium ores of Zimbabwe can be classified into two main types; the seam deposits occurring in the Great Dyke and comprising the major part of the known reserves, and the alpine or podiform deposits which occur as isolated occurrences in ultrabasic intrusions not associated with the Great Dyke. Before considering these ores in more detail it is useful to consider the specific properties which make an ore most suitable for smelting to high-carbon ferrochromium, for this is the most

important of the alloys. The properties of the ores can be sub-divided into chemical and physical properties and the most important of these for high-carbon ferrochromium production are summarised in Table 4.

Table 4 : Properties required in chromium ores for efficient production of high-carbon ferrochromium

property of ore	
chemical	physical
high Cr_2O_3 content	low friability
high Cr:Fe ratio	low decrepitation
high refractory:non-refractory ratio	high bulk density
	high gangue softening or melting temperature

The Cr_2O_3 content determines the grade of the ore and thus the amount of chromium recovered per tonne of ore smelted, whereas the Cr:Fe ratio determines the chromium content of the alloy. The refractory:non-refractory ratio is a ratio which has been investigated at the Institute of Mining Research and it has been found to correlate extremely closely with the chemical reducibility of the ores. In general the more difficult the ore is to reduce, the better it performs in a submerged arc furnace producing high-carbon ferrochromium.

The friability of an ore is its tendency to break or disintegrate into small fragments under the applied and abrasive loads encountered during mining of the ore, during its transportation and within the smelting furnace itself. If large quantities of fine material resulting from the disintegration of a friable ore are added to, or produced within, the furnace these can have a blanketing effect in the charge. This prevents the steady escape of the gases produced and can result in explosive release

of the gases with accompanying ejection of molten material. Apart from the physical danger to personnel and equipment, this condition results in erratic and thus unsatisfactory furnace operation. Friable ores, therefore are not suitable for submerged arc furnace smelting and such ores have to be either fed in gradually with non-friable or lumpy ores at a rate which will not disrupt operations, or if present in large quantities, they must be agglomerated by pelletising or briquetting.

The decrepitation of an ore is its tendency to disintegrate when subjected to thermal shock, such as encountered in the furnace. Thus the effect of an ore which has a high degree of decrepitation is similar to that of a friable ore in producing excessive fines within the furnace.

The bulk density of the ore is controlled not only by the proportion of the heavy chromium and iron constituents to the lighter gangue constituents, but also by its physical condition, in particular its porosity. The bulk density of the ore will to some extent determine whether or not the ore descends deep within the furnace before being reduced, a condition which results in efficient smelting.

Similarly, the gangue softening temperature helps to determine whether the ore will physically maintain its form before being reduced deep within the furnace, or whether the spinel crystals will be released from the gangue at a relatively shallow depth in which case the spinels tend to enter the slag, recovery of alloy may be decreased and there may be problems with the slag due to its increased content of Cr_2O_3 .

Considering first the Great Dyke ores, these can be sub-divided into two groups on the basis of the mean composition of the seams, Table 5.

Table 5 : Chemical groupings of Great Dyke chromium ores for smelting to ferrochromium alloys

mean composition or ratio	Group 1 Seams 1,2 and 3	Group 2 Seams 4-9 (10 and 11)
Cr ₂ O ₃ (%)	43-46	47-51
FeO	17-19	13-17
Cr:Fe	1,9-2,5	2,6-3,5
R:non-R	2,3-3,5	2,8-5,0

R = refractory

The Group 2 ores are characterised by higher contents of Cr₂O₃, higher Cr:Fe ratios and lower FeO contents than the Group 1 ores. The ratio of the refractory:non-refractory components also tends to be greater in the Group 2 ores. These are true high-chromium ores whereas the Group 1 ores are more closely related to the high-iron ores of South Africa.

In smelting the ores to ferrochromium, those in Group 1 will be more easily reduced and thus less power intensive than those in Group 2. However, the relatively low Cr:Fe ratios will result in alloys containing 58%-64% Cr, falling between the charge chrome of 50%-55% Cr produced in South Africa and the high-carbon ferrochromium containing 65%-70% Cr produced from the ores with higher Cr:Fe ratios. The Group 1 ores can be smelted directly to ferrochromium in the composition range indicated, but they should preferably be blended with Group 2 ores in the furnace charge in order to produce a better quality alloy.

The chemical variations between the different podiform ores are complex and they cannot be characterised as simply as the seams on the Great Dyke. Although the range in Cr₂O₃ content is very similar to that of the Great Dyke ores, the mean of 44% Cr₂O₃ is slightly less than the mean of 47% Cr₂O₃ for the Great Dyke ores. However,

The mean Cr : Fe ratio is some what greater at 2,9 (ranging from 1,9 - 4,1), compared with 2,7 (ranging from 2,0 - 3,5) for the Great Dyke ores. This is due to the generally lower content of approximately 12% FeO in the podiform ores compared with approximately 16% FeO in the Great Dyke.

With only two exceptions, ores from the podiform deposits have more favourable physical properties for smelting than most of the Great Dyke ores. For example, the mean friability of the podiform ores is 17%, ranging from 4,5% - 32% whereas mean friability for the Great Dyke ores is 42% ranging from 10% - 92%(9).

Physico-chemical ratings of the ores for smelting.

A favourable combination of chemical and physical properties in the ores results in the most effective production of high-carbon ferrochromium, and thus a system of physico-chemical ratings has been devised in order to assess the individual ores or seams⁽¹⁰⁾. The ratings take into account what are considered to be the important chemical and physical properties required in the ore for submerged arc smelting to high-carbon ferrochromium, most of which have been described briefly in this paper.

Some examples of physico-chemical ratings applied to the seams on the Great Dyke and to the best and the worst of the podiform deposits are given in Table 6.

Table 6 : Examples of physico-chemical ratings applied to the chromite seams on the Great Dyke and to the podiform deposits

deposit or seam	physico-chemical rating (points)	percentage rating
max. rating	900	100
best podiform	769	85
No. 4 seam	662	74
No. 6 seam	613	68
No. 7 seam	530	61
worst podiform	548	61
No. 1 seam	546	61
No. 9 seam	533	59
No. 2 seam	530	59
No. 5 seam	525	58

It is evident that the best of the ores for high-carbon ferrochromium is from a podiform deposit which achieves a rating of 769 points, or 85% of the theoretical maximum. Of the Great Dyke seams, No. 4 Seam is superior to the remaining seams.

It is of interest that apart from No. 4 Seam and to an extent No. 6 Seam, the remaining seams of the Great Dyke achieve very similar ratings, although these may have been achieved through different combinations of favourable or unfavourable properties.

Areas for further exploration and development

From what has already been determined concerning the smelting properties of Zimbabwean chromium ores, several possible areas become evident for further investigation and possible development by potential ferrochromium producers. Foremost is No. 4 Seam which has the best potential on the Great Dyke for high-carbon ferrochromium

production. This seam should be investigated far more extensively in order to determine whether its favourable properties are maintained over its entire length.

If, however, present developments in plasma smelting become commercially viable for the treatment of chromium ores, there may be a revolution in ferrochromium technology. The most significant potential advantage of plasma smelting is that it requires finely divided ores and thus the need for costly agglomeration of the friable ores, which comprise a very large proportion of the Zimbabwean reserves, will fall away. In a plasma smelting plant, the friable ores will come into their own and the suitability of an ore for high-carbon ferrochromium will depend mainly upon its chemical properties. The more friable seams such as No. 7 and No. 9 will then become more important sources for the ore.

Although the reserves of the podiform ores are small in comparison with the Great Dyke ores, their generally outstanding properties for present-day smelting practices should encourage exploration for further deposits not only in the areas in which deposits are known to occur but in new areas which may have potential for the discovery of further deposits.

Metallurgical problems in ferrochromium production in Zimbabwe

There are three main problems associated with the production of high-carbon ferrochromium in Zimbabwe and which are, or will be, common to every producer. These are:-

- 1) The carbon content of the alloy.
- 2) The sulphur content of the alloy.
- 3) The use of friable ores and ore fines.

Higher prices and a distinct market advantage are at present commanded by high carbon ferrochromium which contains less than 6% C, as opposed to the generally

encountered contents of 7%-8% C. Decreased carbon contents in the alloys are achieved only by the use of certain types of ores and the correct smelting conditions. The suitable ores not only have to be what is known as 'hard, lumpy', but they require other specific properties which enable them to have a carbon-refining action on the high-carbon ferrochromium. Such ores occur to a limited extent only in Zimbabwe, and not at all in South Africa, and their presently known reserves are being depleted rapidly. However, the problem of reserves of hard, lumpy refining ores is not peculiar to Zimbabwe alone and already the economic distinction between the high-carbon alloys on the basis of their carbon content is less pronounced and it may disappear totally in the near future.

The sulphur content of Wankie coke tends to be relatively high and consequently the sulphur content of high-carbon ferrochromium may tend to exceed the specified maximum levels. In this case additional procedures are necessary to remove the excess sulphur from the ferrochromium but these will incur extra costs. The most satisfactory solution is to provide a reductant with a low content of sulphur so that the problem does not arise and one of the mining companies in Zimbabwe is now carrying out investigations into a low-sulphur coal deposit from which a char suitable for ferroalloy production can be produced.

The question of friable ores and ore fines is a world-wide problem which is becoming more prominent with the depletion of the World's reserves of the hard, lumpy ores. Greater proportions of friable ore are, of necessity, being charged to submerged arc furnaces, and thus agglomeration facilities, such as briquetting or

pelletising are becoming necessary, involving further pre-treatment costs. Again this problem is not peculiar to Zimbabwe and it is possible that the potential developments in plasma metallurgy which have been mentioned, will change the present physical disadvantage of friable ores to an advantage.

Conclusion

The world is going to be increasingly dependent upon Southern Africa for its supply of chromium. Whether this comes from South Africa with its low grade ores and low mining costs, or from Zimbabwe with high-grade ores but higher mining costs, will depend not only upon the relative economics of production and upon the preference of the steel industries, but also upon the different political climates in both these countries and the degree to which the various Western countries are prepared to rely upon one country only as their main source of a strategically important metal.

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